Optimal monetary policy under menu costs

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Textbook benchmark: Tractable-but-unrealistic Calvo friction

- *Random* and *exogenous* price stickiness

$\Longrightarrow$ **Optimal policy:** Inflation targeting *Woodford 2003; Rubbo 2023*

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Criticism:

- Theoretical critique: Not microfounded
- Empirical critique: State-dependent pricing is a better fit examples

  Nakamura et al 2018; Cavallo and Rigobon 2016; Alvarez et al 2018; Cavallo et al 2023

Optimal policy under menu costs

Our contribution: More realistic (less tractable) menu costs

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  - $\Rightarrow$ Motive for relative prices to change

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- **Stylized analytical model**

- **Quantitative model**

Related literature

- Optimal monetary policy with sectors / relative prices, Calvo

  Aoki 2001, Woodford 2003, Benigno 2004, Wolman 2011, Rubbo 2023

- Menu costs *assuming* inflation targeting, solve for optimal inflation target

  Wolman 2011, Nakov-Thomas 2014, Blanco 2021

- Menu costs + trending productivities (no direct costs)

  Adam and Weber 2023

- Optimal policy with menu costs w/out sectors

  Karadi, Nakov, Nuno, Pasten, and Thaler 2024

- Non-normative menu cost literature
  - Theoretical *Golosov-Lucas 2007; Caballero-Engel 2007; Nakamura-Steinsson 2009; Alvarez-Lippi-Paciello 2011; Midrigan 2011; Gertler-Leahy 2008; Auclert et al 2023*
  - Empirical *Nakamura et al 2018; Cavallo-Rigobon 2016; Alvarez et al 2018; Gautier-Le Bihan 2022*

Roadmap

1. **Baseline model & optimal policy**
2. **Extensions**
3. **Comparison to Calvo model**
4. **Quantitative model**
5. **Conclusion and bigger picture**

Model setup + household's problem

General setup:

- Off-the shelf sectoral model with S sectors
- Each sector is a continuum of firms, bundled with CES technology
- Static model (& no linear approximation)

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$$\max_{C,N,M} \ \ln(C) - N + \ln\left(\frac{M}{P}\right)$$

$$\text{s.t.} \ \ PC + M = WN + D + M_{-1} - T$$

$$C = \prod_{i=1}^{S} c_i^{1/S}$$

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Optimality conditions:

$$c_i = \frac{1}{S}\frac{PC}{p_i}$$

$$PC = M$$

$$W = M$$

Intermediate firms: price setting with menu costs

Technology: firm $j \in [0, 1]$ in sector i

$$y_i(j) = A_i \cdot n_i(j)$$

Demand: $y_i(j) = y_i \left(\frac{p_i(j)}{p_i} \right)^{-\eta}$

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Menu cost: ψ extra units of labor

- χ_i: indicator for price change

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$\implies$ **Direct cost of menu costs:** excess disutility of labor

$$N = \sum_i n_i + \psi \sum_i \chi_i$$

- Other specifications do not affect result ▸ more

Menu costs induce an inaction region

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- if adjusting: price $=$ nominal marginal cost

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Inaction region: don't adjust iff $p_i^* = \frac{W}{A_i}$ close to p_i^{old}

Optimal policy after a productivity shock

Formal planner's problem

- Start at steady state: all sectors have $A_i^{ss} = 1 \;\; \forall i$, so $p_i^{ss} = W^{ss} \equiv 1$

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Proposition 1: there exists a threshold level of productivity $\overline{A}$ s.t.:

- If shock is not too small, $A_1 \geq \overline{A}$, optimal policy is nominal wage targeting:

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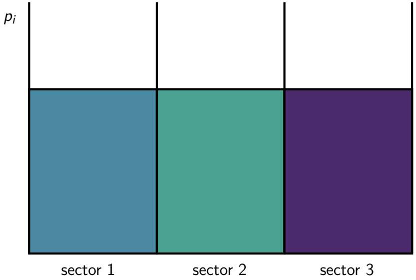
- If shock is small, $A_1 < \overline{A}$, then optimal policy ensures no sector adjusts:

$$p_i = p_i^{ss} \ \forall i$$

Large-enough shocks

Recall: $p_i^* = MC_i = \frac{W}{A_i}$



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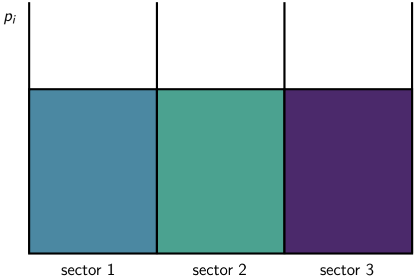

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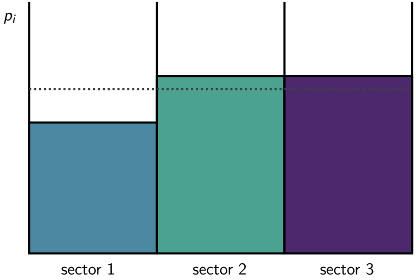

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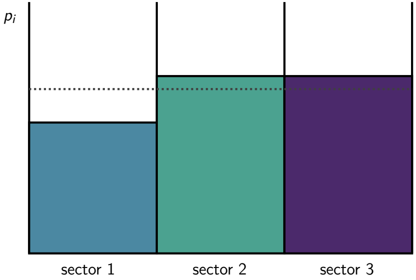

Inflation targeting
$\mathbb{W}^f - S\psi$

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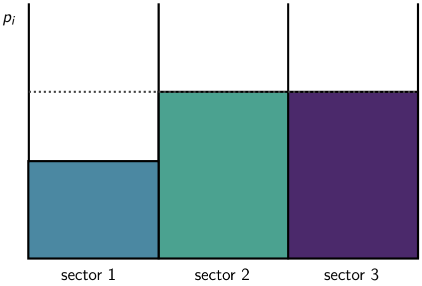

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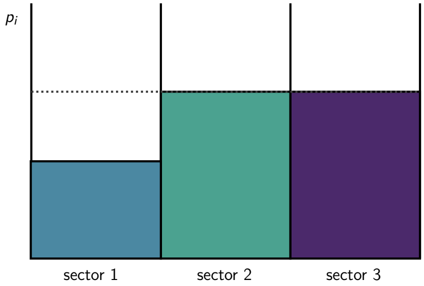

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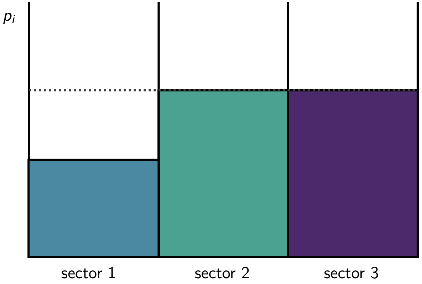

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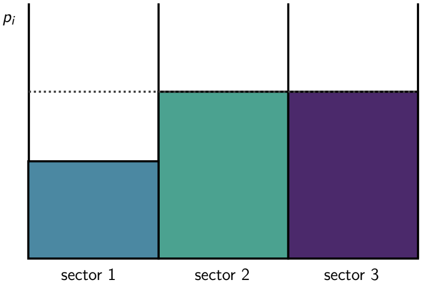

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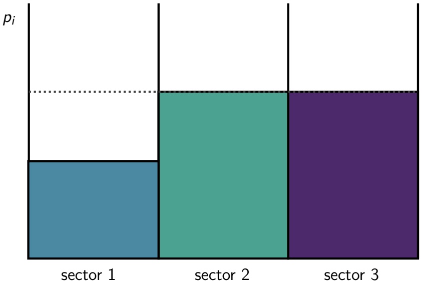

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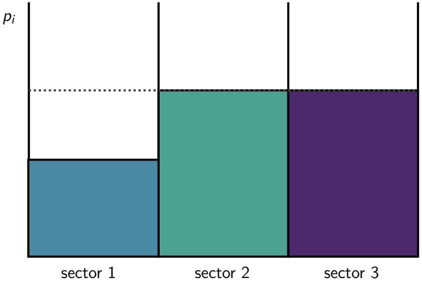

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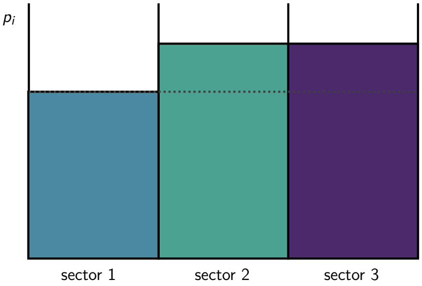

Only sectors k adjusts
$\mathbb{W}^f - (S-1)\psi$

Small shocks: state dependent optimal policy

▸ math

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Lemma 2: $\exists\ \overline{A}$ such that

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{none adjust}}$$

iff $A_1 > \overline{A}$. Furthermore, $\overline{A}$ is increasing in ψ.

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welfare loss of inflation targeting

Summary: at least 0.5% of firm revenues, plausibly much more

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(1) Measure *frequency of price adjustment*

(2) Build structural model

(3) $\Longrightarrow$ *calibrate* menu costs to fit

Nakamura and Steinsson (2010):

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2. Direct measurement. For *physical* adjustment costs,

Levy et al (1997, QJE): 5 grocery chains

- 0.7% revenue

Dutta et al (1999, JMCB): drugstores

- 0.6% revenue

Zbaracki et al (2003, Restat): mfg

- 1.2% revenue

Extensions

- Generalized functional forms
- Multiple shocks / production networks
- Heterogenous costs ▸ more
- Sticky wages

Generalization: stabilize nominal MC of unshocked firms

Generalized model:

- Any (HOD1) aggregator:
  $C = F(c_1, ..., c_S)$
- DRS production technology:
  $y_i(j) = A_i n_i(j)^\alpha$, $\alpha \in (0, 1]$
- Any preferences quasilinear in labor:
  $U\left(C, \frac{M}{P}\right) - N$

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Nominal MC:

$$MC_i(j) = \left[\alpha \frac{W}{A_i^\alpha} \left(y_i p_i^\eta\right)^{\alpha - 1}\right]^\theta$$

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Extended Proposition 1:

Stabilize **nominal marginal costs of unshocked firms** $\Longrightarrow Y\uparrow, P\downarrow$

Production networks

Baseline model:

- Production technology:

$$y_i = A_i n_i$$

Roundabout production network:

- Production technology:

$$y_i = A_i n_i^{\beta} I_i^{1-\beta}$$
$$I_i = \prod_{k=1}^{S} I_i(k)^{1/S}$$

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$$MC_i = \kappa \frac{W^{\beta} P^{1-\beta}}{A_i}$$

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- Nominal MC of unshocked sectors $\equiv W$

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- Nominal MC of unshocked sectors $\equiv W^{\beta} P^{1-\beta}$

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- *Why* then is optimal policy in multisector Calvo **inflation targeting?** *Aoki, Rubbo*

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- **Menu costs are *nonconvex*:**

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

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- **Menu costs are *nonconvex*:**

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- **With *convex* menu costs:**

e.g. Rotemberg, $\psi \cdot (p_i - p_i^{ss})^2$

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- **Menu costs are *nonconvex*:**

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- Labor market clearing:

$$N = \sum n_i + \psi \sum \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- **With *convex* menu costs:**

e.g. Rotemberg, $\psi \cdot (p_i - p_i^{ss})^2$

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Why not inflation targeting?

- *Why* then is optimal policy in multisector Calvo inflation targeting? *Aoki, Rubbo*

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$$\Delta \equiv \sum_{i=1}^{S} \int_0^1 \left[\frac{p_i(j)}{p_i}\right]^{-\eta} dj$$

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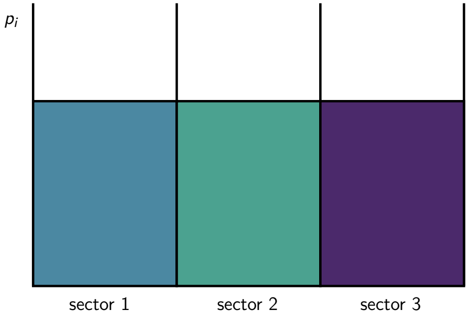
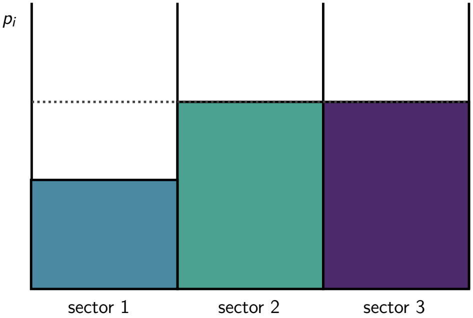
Convex costs $\Longrightarrow$ *smooth* price changes across sectors

Calvo diagram: shocking sector-1 productivity



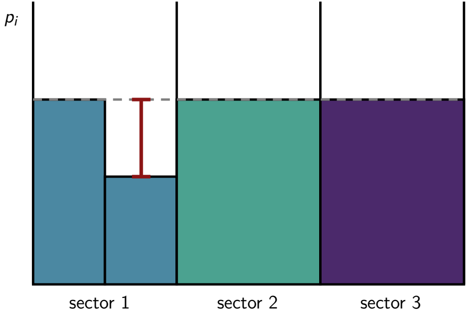
Steady state



Flexible prices, after shock

Calvo diagram: shocking sector-1 productivity

▸ math

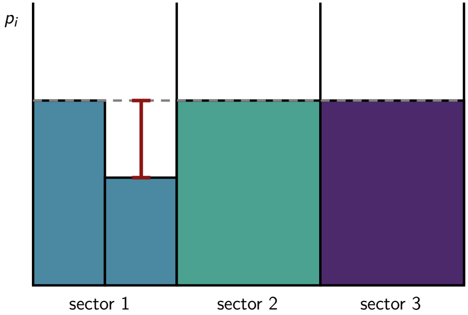


Nominal wage targeting under Calvo

Lots of price dispersion: *only* one sector

Calvo diagram: shocking sector-1 productivity

▸ math



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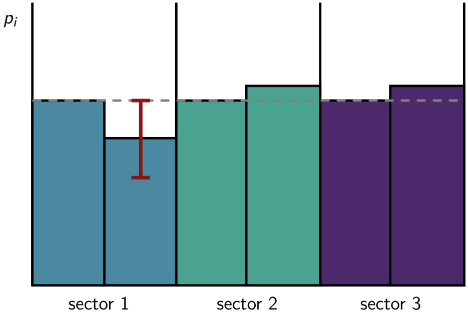

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Lots of price dispersion: *only* one sector

Little price dispersion: *all* sectors

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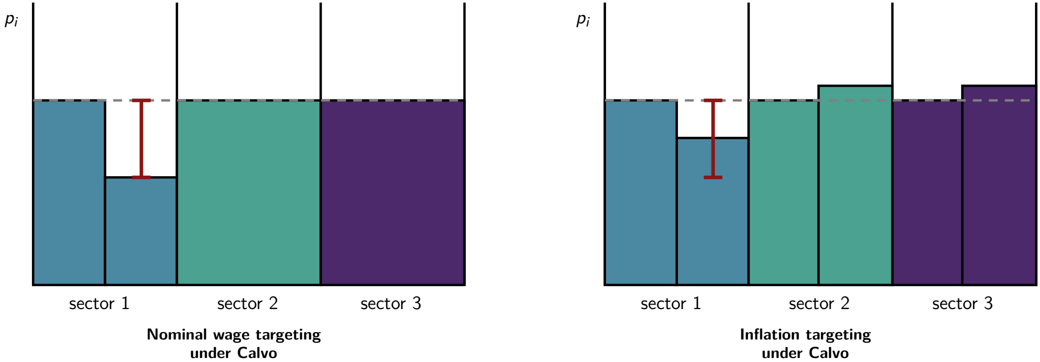

Lots of price dispersion: *only* one sector

Little price dispersion: *all* sectors

Convex costs $\Longrightarrow$ *smooth* price changes across sectors

Quantitative model: setup

Dynamic model, **idiosyncratic** + sectoral shocks, and **Calvo plus** price setting

Household

$$\max_{\{C_t,N_t,B_t,M_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \omega \frac{N_t^{1+\varphi}}{1+\varphi} + \ln\left(\frac{M_t}{P_t}\right) \right]$$

$$\text{s.t.} \qquad P_t C_t + B_t + M_t \leq R_t B_{t-1} + W_t N_t + M_{t-1} + D_t - T_t$$

Firms

* final and sectoral good producers: same as in static model

Quantitative model: intermediate firms

Intermediate firms: **idiosyncratic** shocks, **Calvo+** price setting

$$\max_{p_{it}(j),\chi_{it}(j)} \quad \sum_{t=0}^{\infty} \mathbb{E}\left[\frac{1}{R^t P_t}\left\{p_{it}(j)\, y_{it}(j) - W_t n_{it}(j)\,(1-\tau) - \chi_{it}(j)\psi W_t\right\}\right]$$

$$\text{s.t.} \quad y_{it}(j) = A_{it} a_{it}(j)\, n_{it}(j)^{\alpha}$$

$$\psi_{it}(j) = \begin{cases} \psi & \text{w/ prob. } 1-\nu \\ 0 & \text{otherwise} \end{cases}$$

productivity distribution is mixture between AR(1) and uniform (**fat tail**)

$$\log\left(a_{it}(j)\right) = \begin{cases} \rho_{\text{idio}} \log\left(a_{it-1}(j)\right) + \varepsilon_{it}^{\text{idio}}(j) & \text{with prob. } 1-\varsigma \\ \mathcal{U}\left[-\log\left(\underline{a}\right), \log\left(\overline{a}\right)\right] & \text{with prob. } \varsigma \end{cases}$$

Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and

	Parameter (monthly frequency)	Value	Target
β	Discount factor	0.99835	2% annual interest rate
ω	Disutility of labor	1	standard
φ	Inverse Frisch elasticity	0	Golosov and Lucas (2007)
γ	Inverse EIS	2	standard
S	Number of sectors	6	Nakamura and Steinsson (2010)
η	Elasticity of subst. between sectors	5	standard value
α	Returns to scale	0.6	standard value
τ	Labor subsidy	0.2	$1/\eta$

Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and (2) calibrated by SMM targeting

	Parameter (monthly frequency)	Value	Target
β	Discount factor	0.99835	2% annual interest rate
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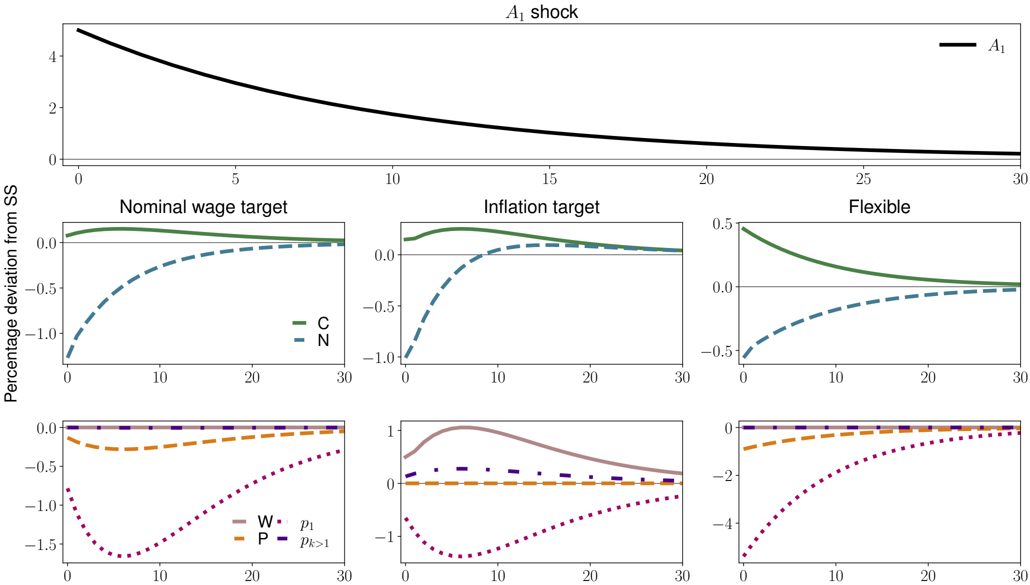
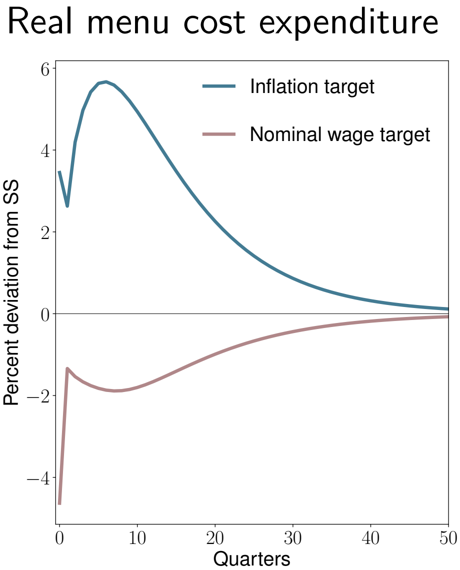
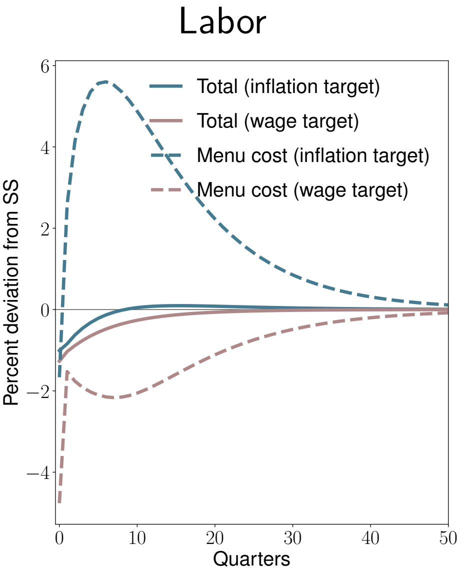
α	Returns to scale	0.6	standard value
τ	Labor subsidy	0.2	$1/\eta$
σ_{idio}	Standard deviation of idio. shocks	0.044	menu cost expenditure / revenue 1%(1.1%)
ρ_{idio}	Persistence of idio. shocks	0.995	share of price changers 8.7% (8.3%)
ψ	Menu cost	0.1	median absolute price change 8.5% (8.7%)
ν	Calvo parameter	0.075	Q1 absolute price change 4.5% (4.2%)
ς	Fat tail parameter	0.0016	Q3 absolute price change 20.4% (14.8%)
			kurtosis of price changes 3.609 (2.755)

Exercise: perfect foresight sectoral shock



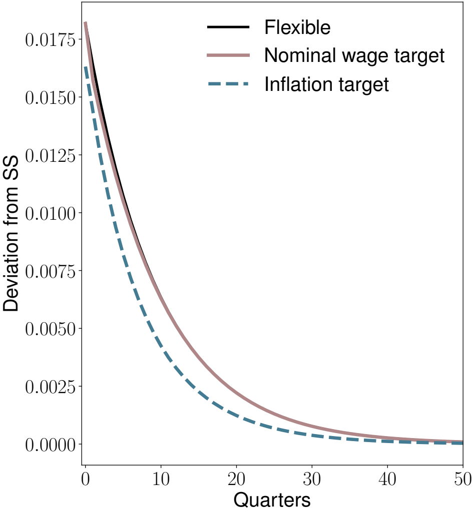
Policy comparison: menu cost expenditure





Policy comparison: welfare

Welfare response to A_1 shock



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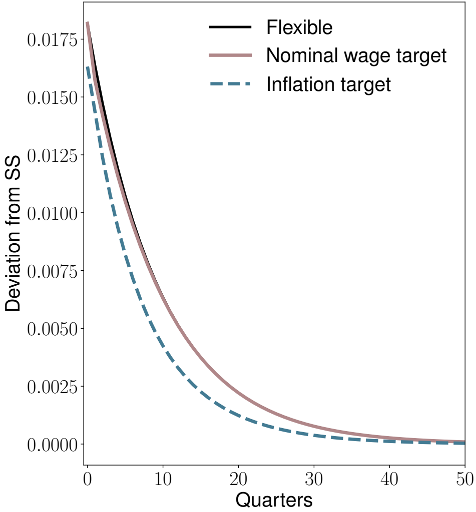

- Consider welfare under W targeting

Policy comparison: welfare

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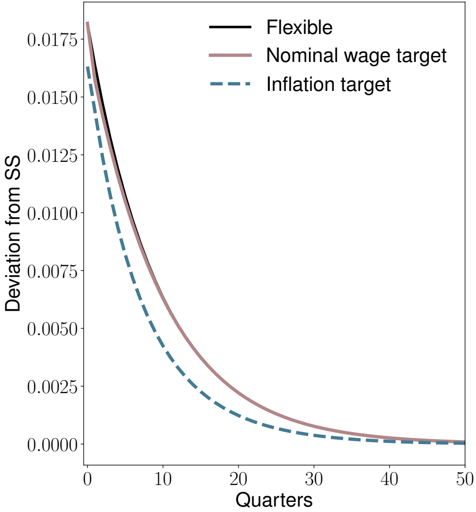
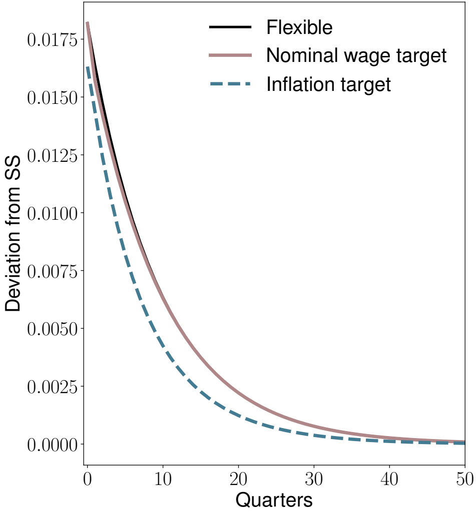


- Consider welfare under W targeting
- How much extra C is needed to match welfare under flexible prices?

$$\sum_t \beta^t\, U\left((1+\lambda)\, C_t,\ N_t\right) = \sum_t \beta^t\, U\left(C_t^{\text{flex}},\ N_t^{\text{flex}}\right)$$

Policy comparison: welfare

Welfare response to A_1 shock



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Policy comparison: welfare

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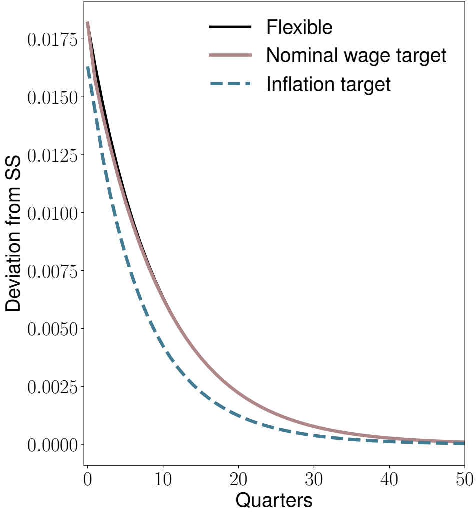

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$$\lambda^W = 0.002\%$$
$$\lambda^P = 0.025\%$$

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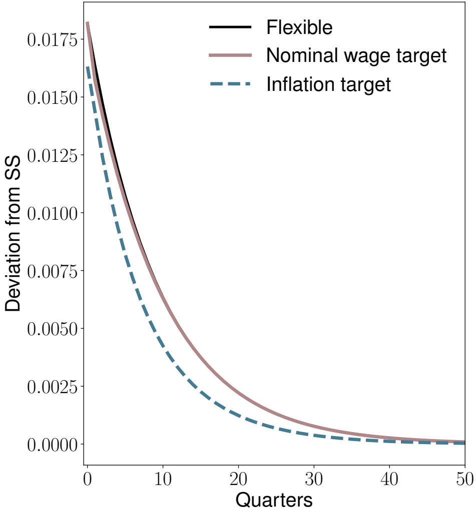
Welfare response to A_1 shock



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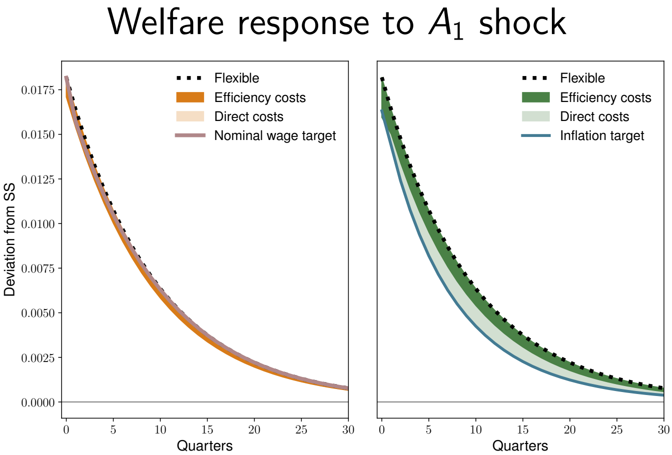
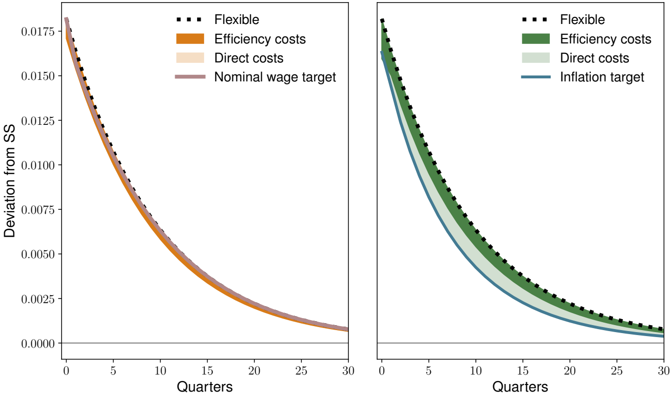
Decomposing welfare



1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs
2. **Efficiency costs:** welfare loss from incorrect relative prices

Decomposing welfare

Welfare response to A_1 shock



1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs

2. **Efficiency costs:** welfare loss from incorrect relative prices

- Direct costs: $\tilde{\lambda}^W = 0.008\%$ and $\tilde{\lambda}^P = 0.013\%$
- **Interpretation:** improvement from both channels

Numerically-optimal policy in simple class of rules

Consider monetary policy rules stabilizing:

$$W^{\xi} P^{1-\xi}$$

$$\xi \in [0, 1]$$

Recall λ: "how much extra C needed to match welfare response of flex-price economy?"

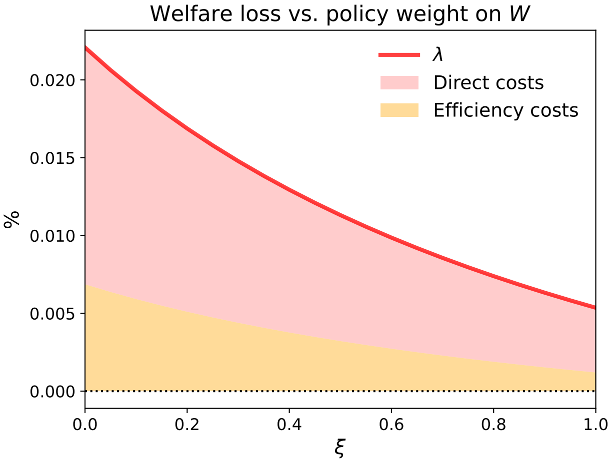
Numerically-optimal policy in simple class of rules

Consider monetary policy rules stabilizing:

$$W^{\xi} P^{1-\xi}$$
$$\xi \in [0, 1]$$

Recall λ: "how much extra C needed to match welfare response of flex-price economy?"

Numerically-optimal policy: Stabilize W alone



Conclusion

Inflation should be countercyclical after sectoral shocks

Rationale:

- Inflation targeting **forces firms to adjust unnecessarily**, which is costly
- Nominal wage targeting does not and still achieves "correct" relative prices

Conclusion

Inflation should be countercyclical after sectoral shocks

Rationale:

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- Nominal wage targeting does not and still achieves "correct" relative prices

This aligns with the implications of other recent work:

- Calvo sticky wages
- Incomplete markets/financial frictions: Sheedy (2014), Werning (2014)
- Information frictions: Angeletos and La'O (2020)
- Sticky prices [**new**]: **Caratelli and Halperin (2024)**

Thank you!

Formally: Social planner's problem

back

$$\max_{X\in\{A,B,C,D\}} \mathbb{U}^X$$

$$\mathbb{U}^A = \left\{ \begin{array}{cc} \max\limits_{M} & \ln[M] - M\left[S-1+1/\gamma\right] \\ \text{s.t.} & \min(\gamma\lambda_1,\lambda_2) \leq M \leq \max(\gamma\lambda_1,\lambda_2) \end{array} \right\}$$

$$\mathbb{U}^B = \left\{ \ln\left[\frac{1}{S}\gamma^{1/S}\right] - 1 - \psi \right\}$$

$$\mathbb{U}^C = \left\{ \begin{array}{cc} \max\limits_{M} & \ln\left[\left(\frac{\gamma}{S}\right)^{\frac{1}{S}} \cdot M^{\frac{S-1}{S}}\right] - \left[(S-1)M + \frac{1}{S}\right] - \frac{1}{S}\psi \\ \text{s.t.} & \lambda_1 < M < \min(\gamma\lambda_1,\lambda_2) \end{array} \right\}$$

$$\mathbb{U}^D = \left\{ \begin{array}{cc} \max\limits_{M} & \ln\left[S^{\frac{1-S}{S}} M^{\frac{1}{S}}\right] - \left[\frac{S-1}{S} + \frac{M}{\gamma}\right] - \frac{S-1}{S}\psi \\ \text{s.t.} & \max(\gamma\lambda_1,\lambda_2) < M < \gamma\lambda_2 \end{array} \right\}$$

$$\text{where } \lambda_1 = \frac{1}{S}\left(1-\sqrt{\psi}\right), \quad \lambda_2 = \frac{1}{S}\left(1+\sqrt{\psi}\right)$$

Adjustment externalities

back

Example: Social planner's *constrained* problem for "neither adjust"

$$\max_{M} U\left(C(M), N(M)\right) \tag{1}$$

$$\text{s.t. } D_1^{\text{adjust}} < D_1^{\text{no adjust}} \tag{2}$$

$$D_k^{\text{adjust}} < D_k^{\text{no adjust}} \tag{3}$$

$\implies M^*_{\text{unconstrained}}$

Social planner's *unconstrained* problem: maximize (1), without constraints

$\implies M^*_{constrained}$

Adjustment externality: $M^*_{\text{unconstrained}} \neq M^*_{\text{constrained}}$

Alternative menu cost formulations

back

Labor costs: Welfare mechanism is *higher labor*

$$\text{profits}_i - W\psi \cdot \chi_i$$
$$\implies N = \sum n_i + \psi \sum \chi_i$$

Real resource cost: Welfare mechanism is *lower consumption*

$$\text{profits}_i \cdot (1 - \psi \cdot \chi_i)$$
$$\implies C = Y\left(1 - \psi \sum_i \chi_i\right)$$

Direct utility cost: Welfare mechanism is *direct*

$$\text{utility} - \psi \cdot \sum \chi_i$$

Heterogeneity: a monetary “least-cost avoider principle”

‣ back

Proposition 5: Suppose sector i has mass S_i and menu cost ψ_i. Suppose further

$$S_1\psi_1 < \sum_{k>1} S_k\psi_k.$$

Then optimal policy is exactly as in proposition 1, modulo changes in $\overline{A}$.

- *Proof:* Follows exactly as in proof of proposition 1.

Heterogeneity: a monetary "least-cost avoider principle"

▸ back

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- *Proof:* Follows exactly as in proof of proposition 1.

Interpretation 1: monetary "least-cost avoider principle"

Interpretation 2: "stabilizing the stickiest price"

Multiple shocks: general case

back

Proposition 7: Consider an arbitrary set of productivity shocks to the baseline model, $\{A_1, ..., A_S\}$.

- Conditional on sectors $\Omega \subseteq \{1, ..., S\}$ adjusting, optimal policy is given by setting $M = M^*_\Omega \equiv \frac{S-\omega}{\sum_{i \notin \Omega} \frac{1}{A_i}}$, where $\omega \equiv |\Omega|$.
- The optimal set of sectors that should adjust, Ω^*, is given by comparing welfare under the various possibilities for Ω, using $\mathbb{W}^*_\Omega$ defined in the paper.
- Nominal wage targeting is exactly optimal if the set of sectors which should not adjust are unshocked: $A_i = 1 \;\; \forall i \notin \Omega^*$.

Price adjustment frequency tracks inflation

back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation
Menu cost models: frequency of price adjustment ↑ if inflation ↑

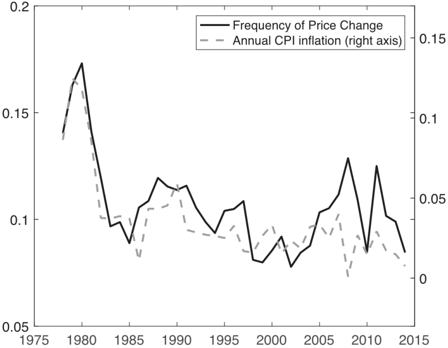

FIGURE XIV

Frequency of Price Change in U.S. Data

Figure: Nakamura et al (2018)

Price adjustment frequency tracks inflation

back

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Menu cost models: frequency of price adjustment ↑ if inflation ↑

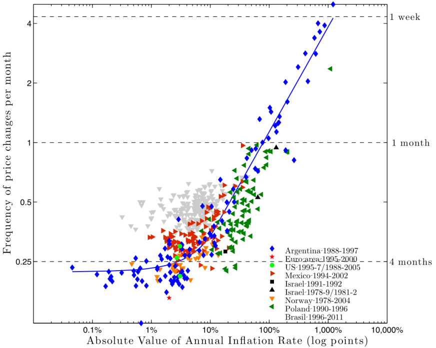

FIGURE VI

The Frequency of Price Changes (λ) and Expected Inflation: International Evidence

Figure: Alvarez et al (2018)

Price adjustment frequency tracks inflation

back

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(a) Frequency of Adjustment

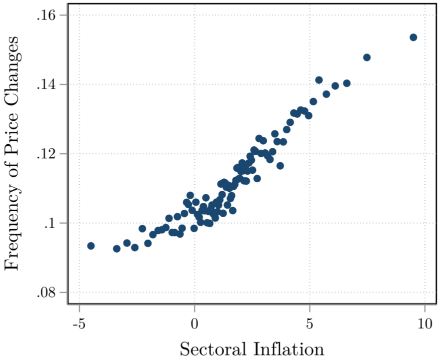

Figure: Blanco et al (2022)

Price adjustment frequency tracks inflation

▸ back

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Figure 1: Frequency of price changes

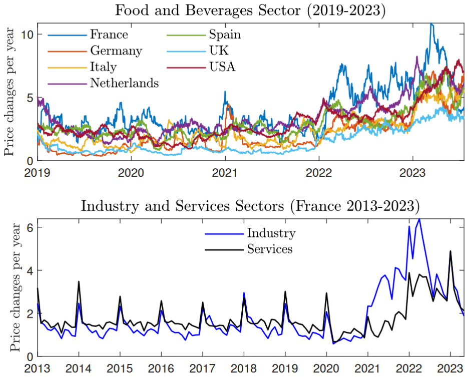
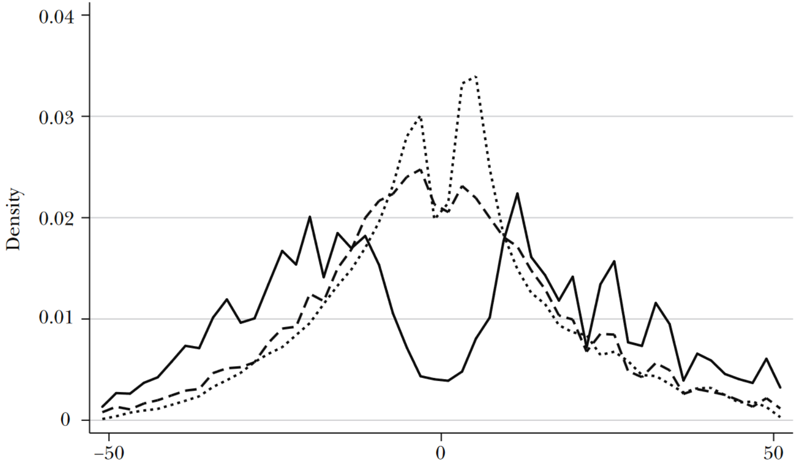


Figure: Cavallo et al (2023)

Evidence of inaction regions

Figure 8

The Distribution of the Size of Price Changes in the United States



The welfare loss of inflation targeting

back

"Inflation targeting": $P = P^{ss}$ (while having correct relative prices)

Proposition 2: Suppose $A_1 > \overline{A}$.
Then:

- Inflation targeting requires all sectors adjust their prices
- Welfare loss from inflation targeting $\propto$ size of menu costs

$$\mathbb{W}^* - \mathbb{W}^{\mathsf{IT}} = (S-1)\psi$$

The welfare loss of inflation targeting

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What are menu costs?

- **Physical adjustment costs.** Baseline interpretation.

The welfare loss of inflation targeting

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$$\mathbb{W}^* - \mathbb{W}^{\mathrm{IT}} = (S-1)\psi$$

What are menu costs?

- **Physical adjustment costs.** Baseline interpretation.
- **Information costs.** Fixed costs of information acquisition / processing.
  - Results unchanged
- **Behavioral costs.** Consumer *distaste* for price changes.
  - Results unchanged